National Aeronautics and
Space Administration

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SEARCH FOR RADIO EMISSIONS FROM EXTRASOLAR PLANETS

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Outline

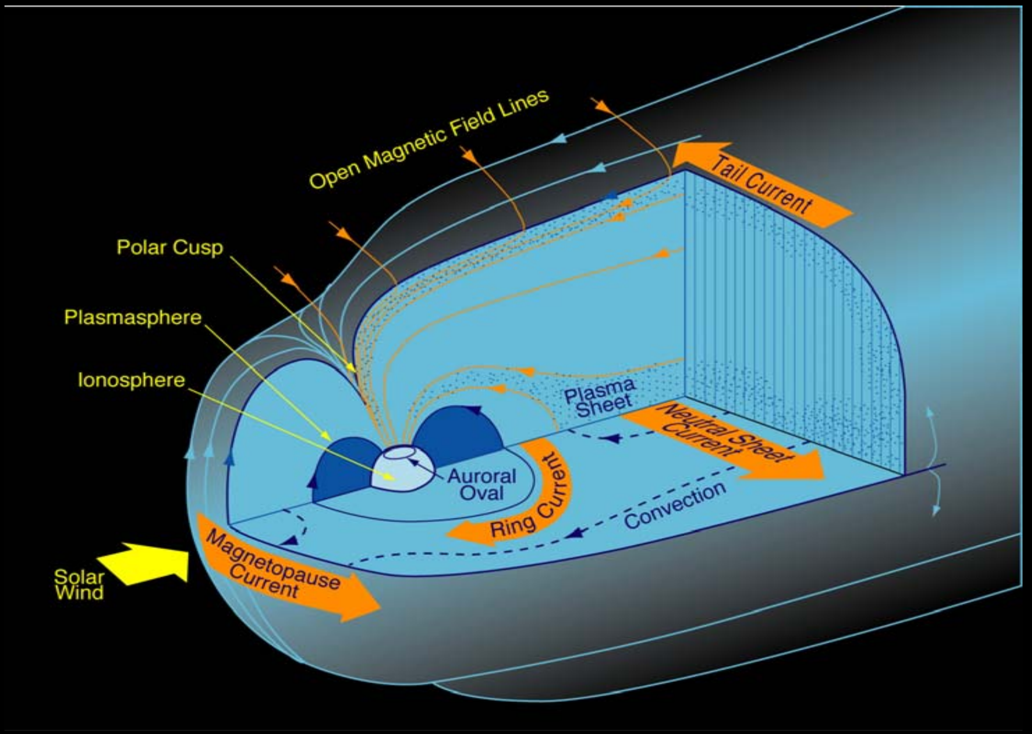
- Introduction
- Planetary Magnetospheres
- Planetary Radio Emission in Solar System
- Extrasolar Planetary Radio Emission: Predictions
- Observational Status
- Technology & Future Observatories
- Summary

Why?

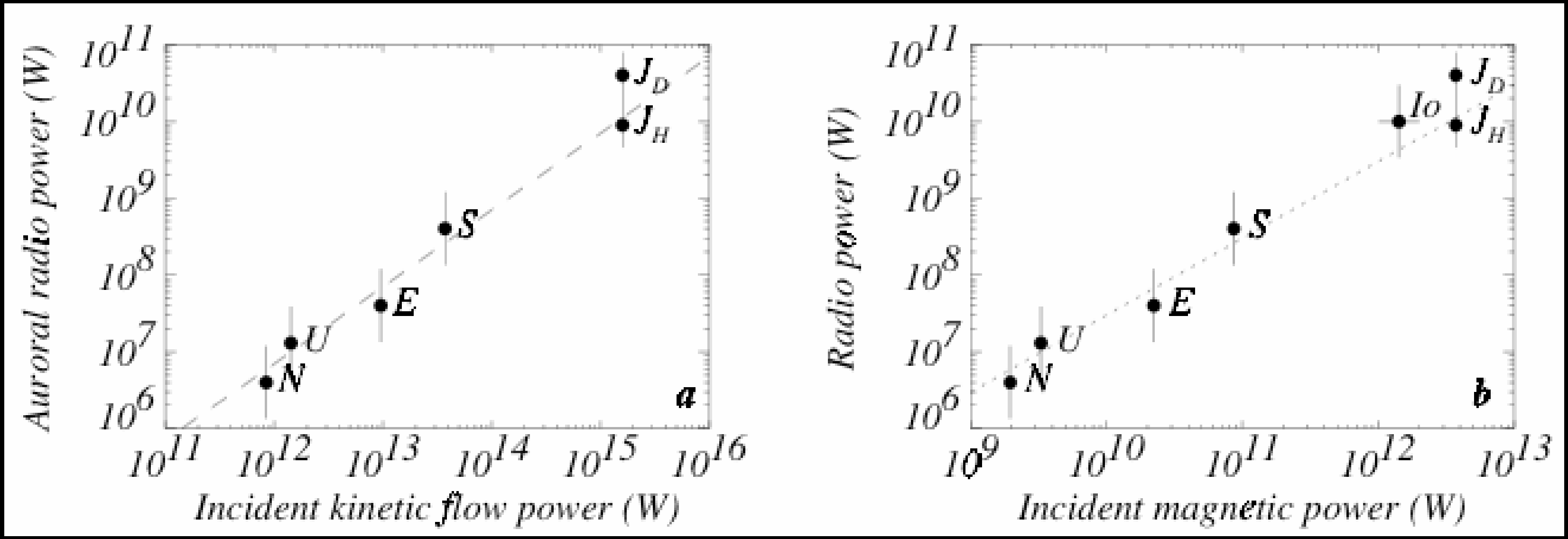
- **Alternate way to search for extrasolar planets (prefers stellar activity, whereas optical requires quiet stars).**
- **Better intensity ratio of stellar flux to planetary flux than in the visible range (10^9) or in the infrared (10^6): between 10^{-4} (quiet sun) and 10^3 (strong radio bursts).**
- **Emissions will quantify planetary B, info re thermal state and composition of planetary interior.**
- **Estimate of plasma density in the magnetosphere**
- **Information on planetary rotation (modulation of the emission with the rotation frequency)**
- **Existence of satellites (plus their orbit)**
- **Star/Planet interaction**

Planetary Magnetospheres

- **Magnetic planets:**
  - **Earth, Jupiter, Saturn, Uranus, & Neptune**
- **Magnetic field generated by rotation of conducting fluid**
- **Magnetic field immersed in solar wind**
- **Pressure from solar wind impacts magnetic field and deforms it**
  - **Currents travel down highly conductive magnetic field lines and deposit energy in polar auroral region**
  - **1% of auroral input energy into electron cyclotron radio emission (Gurnett 1974)**



Radiometric Bode's Law

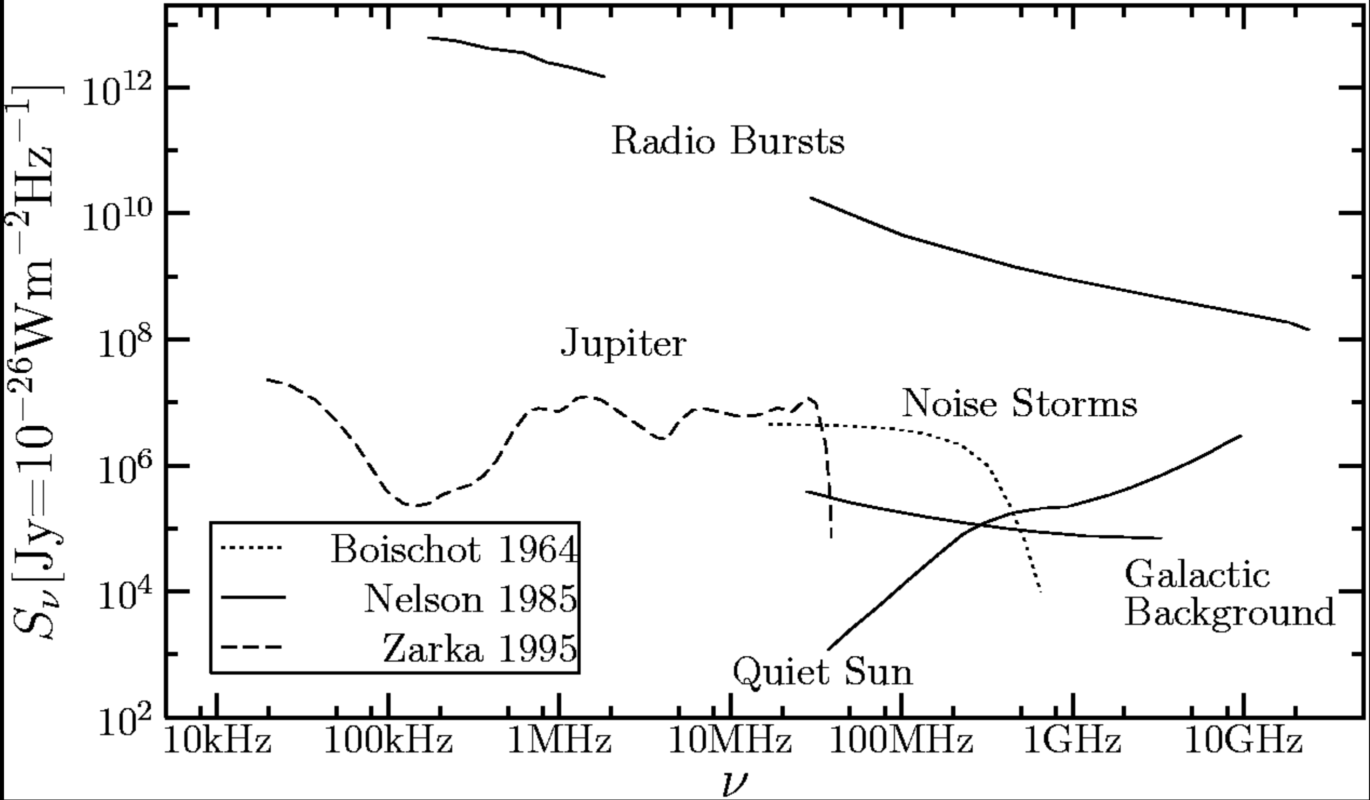


(a) Initial radio Bode's law for the auroral radio emissions of the five radio planets (Earth, Jupiter, Saturn, Uranus and Neptune) [Desch & Kaiser, 1984; Zarka, 1992]. J_D and J_H correspond resp. to the decameter and hectometer Jovian components. The dashed line has a slope of 1 with a proportionality constant of 7×10^{-6} . Error bars correspond to the typical uncertainties in the determination of average auroral radio powers.

(b) Magnetic radio Bode's law with auroral and Io-induced emissions. The dotted line has a slope of 1 with a constant of 3×10^{-2}.

[from Zarka, 2001]

Jovian Radio Emission



The **quiet sun** emission is due to thermal emission of ionized plasma close to the (local) electron plasma frequency. It is randomly polarized.

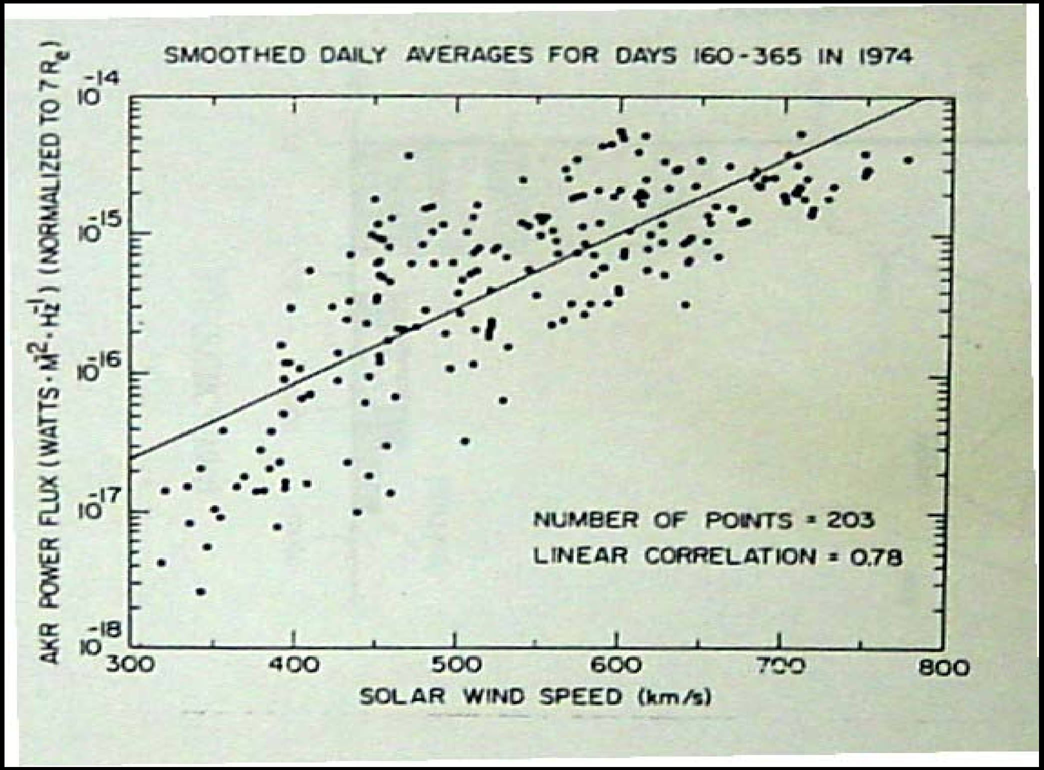
During solar maximum, **noise storms** frequently occur (about 10% of the time). The typical duration is between a few hours and several days. The emission consists of a broadband continuum plus short-lived bursts. The emission is circularly polarized.

Radio bursts are generated by high-energy particles originating from solar flares or shock fronts. Typically, their frequency drifts. Their flux densities are much higher than that of the quiet sun or of noise storms. Different kinds of radio bursts exist.

Variability of Planetary Radio Emission

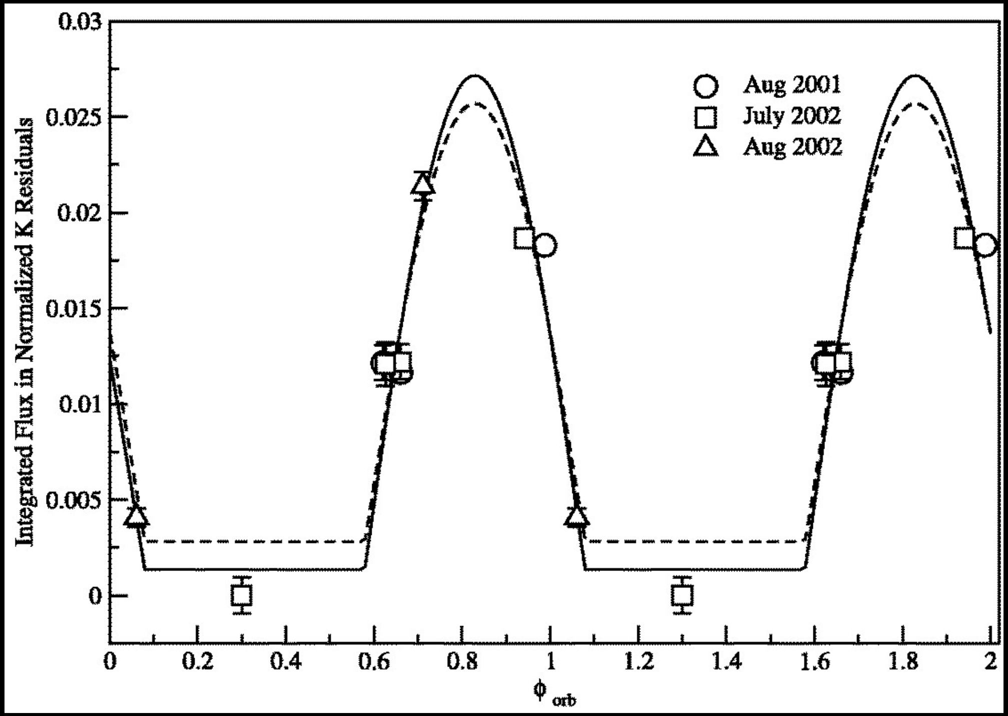
- Planetary radio sources behave as exponential amplifiers (Gallagher & D'Angelo 1979)
- Other stars may have a higher activity than the Sun, i.e., more stellar wind.

Earth cyclotron emission exponential variation with solar wind speed



Observational Status

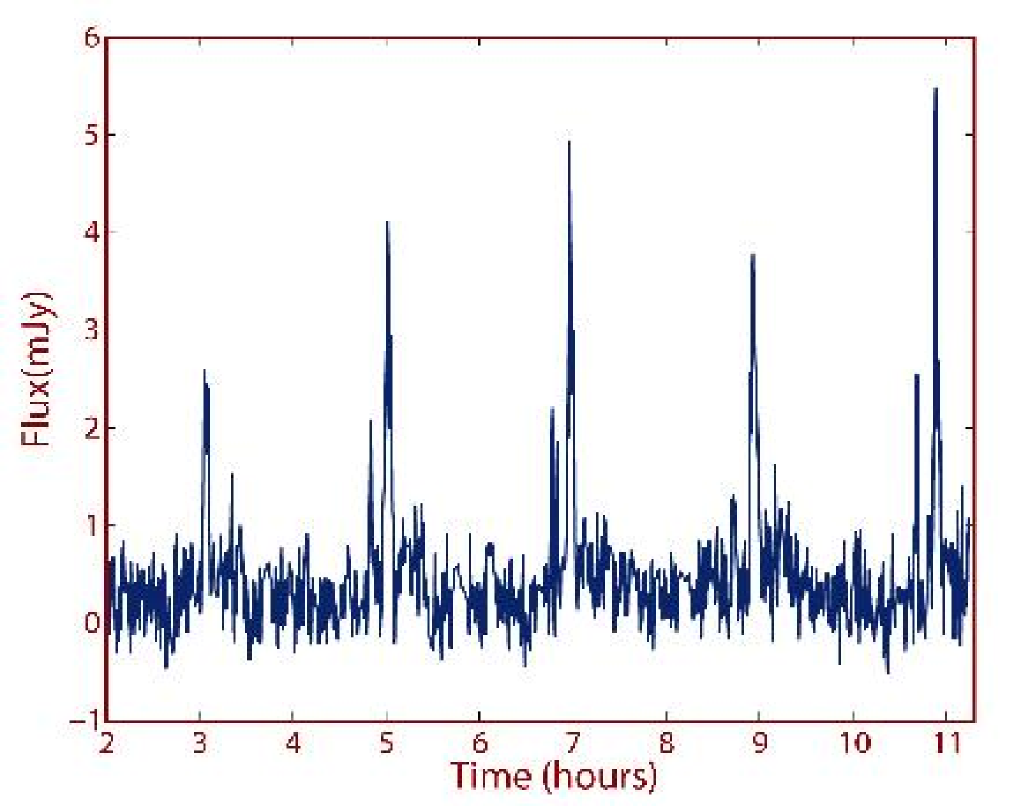
- **Observation of magnetically induced hot spots on HD 179949 + (Shkolnik et a. 2003, 2005, 2008)**



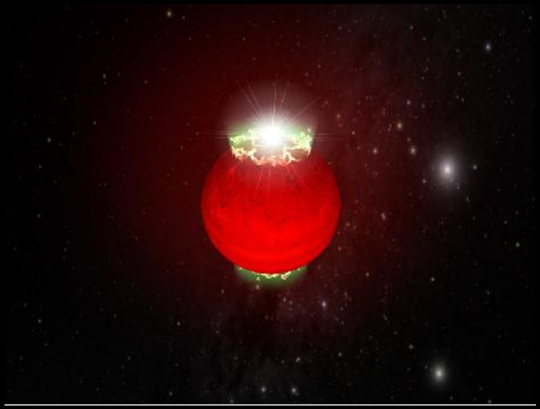
- Observed Ca II H and K lines.
- HD 179949 is 0.8 M planet in 3.1 day orbit
- 4% variation in line strength
- Five year observation
- B-field not estimated

Observational Status

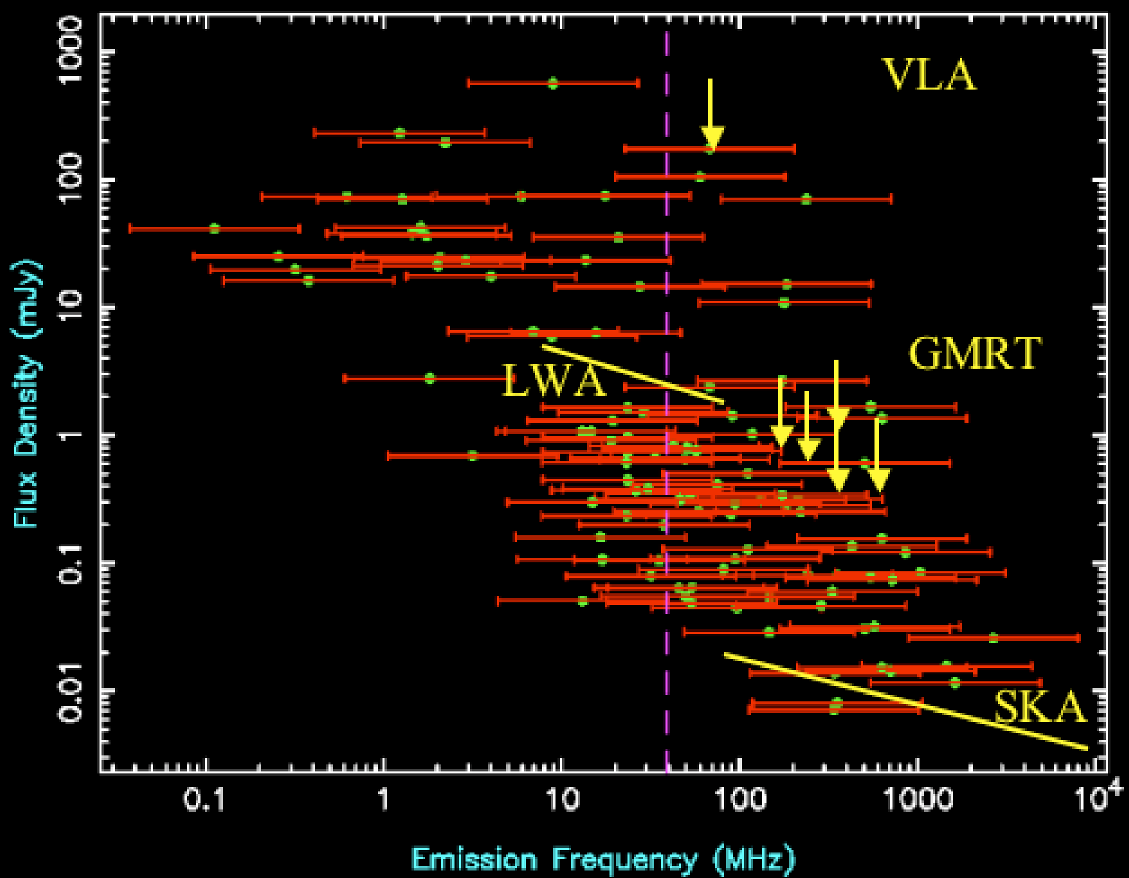
- **Observation of magnetically induced radio emission from brown dwarf TVLM 513-46546 (Hallinan et al. 2007)**



- Pulsed emission with period ~2 hrs.
- Electron cyclotron maser coherent radio emission



Extrasolar Planetary Radio Emission: Predictions



[Lazio, Farrell et al. 2004]

More recent analysis by Griessmeier et al. 2007: four different models for planetary emission

- Clark Lake @ 26 MHz, 22 nearby stars (Yantis et al. 1977)
- UTR-2 @ 25 MHz reached ~ 200 mJy (Ryabov et al. 2004)
- GMRT @ 150 MHz reaching tens of mJy (George & Stevens 2007; Winterhalter et al.)
- VLA @ 74 MHz reaching hundreds of mJy (Bastian et al. 2000; Farrell et al. 2004; Lazio & Farrell 2008)

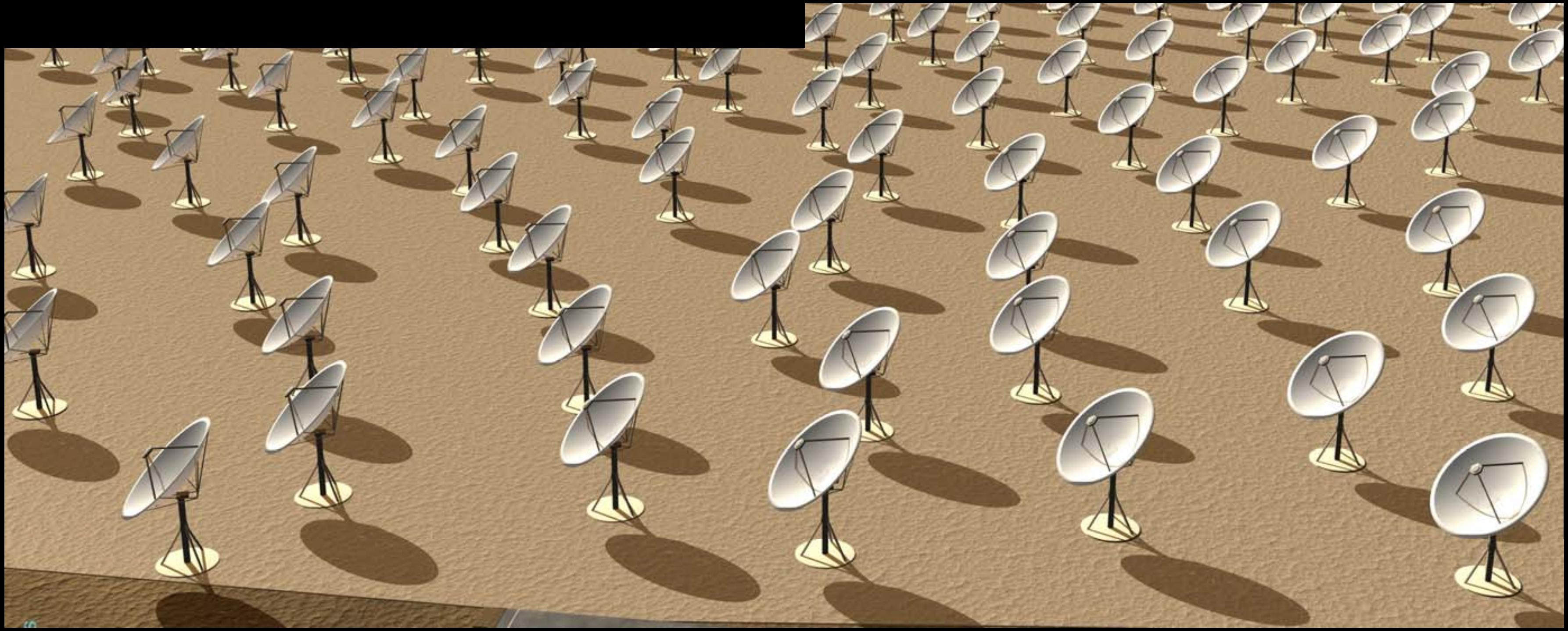
Near Term Instruments (LWA & LOFAR)

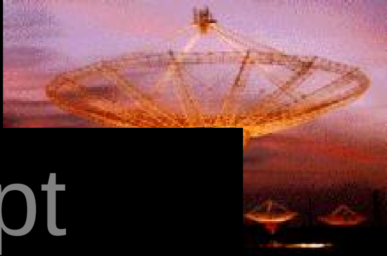
- 20–80 MHz
- Dipole-based array stations
- 50 stations across New Mexico
- 400-km baselines ⇒ arcsecond resolution

- NE Netherlands
- Dipole-based array stations
- 20–80 MHz
- Baselines up to 100 km

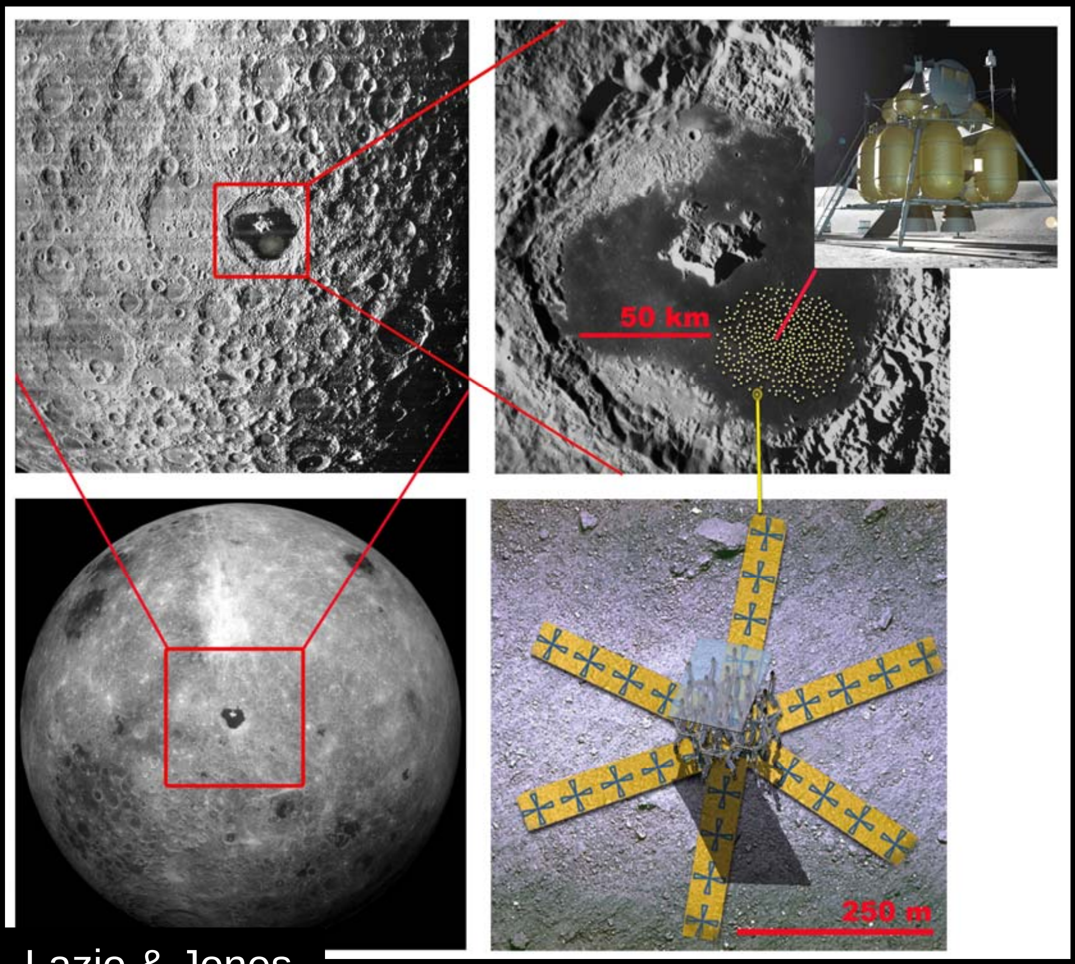
Future Instruments (SKA)

- 100 x sensitive than VLA
- Frequency range: 0.1 - 25 GHz
- Site and design studies ongoing





Far-Side Lunar Array Concept



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- **Science driver: <u>Epoch of reionization and also</u> radio emission from exoplanets**
- **Solves RFI problem**
- **Observations below the Earth's ionospheric cutoff frequency**
- **Technical issues**
  - **Very low power electronics**
  - **Systems operating over extreme temp ranges (-200C to +125C)**
  - **High energy density-low mass batteries**
  - **Low-mass, autonomous, robust deployment systems (rovers)**
  - **Wide-band (Gb/s) data downlink**

Summary

- Exciting discovery of many extrasolar planets
- Detecting radio emission will be direct observation
  - Presence of and strength of magnetic field
  - Rotation
  - Composition
  - Habitability and Sheltering
- GMRT most sensitive array at low frequencies (at the moment)
- Why no detections yet?
  - Telescope sensitivity and frequency coverage
  - Variability
  - Radiometric Bode's law does not apply outside solar system
  - Weak magnetic fields
  - …
- New instruments in radio band

THE END

Exoplanet Radio Emission

Theoretical studies have proposed scaling "laws" to estimate the radio power (P_r) emitted from solar (stellar) wind driven cyclotron emissions*:

$$P_r \propto \left(\frac{m}{m_j}\right)^{1.33} \left(\frac{d}{d_j}\right)^{-1.60} \left(4X10^{11}\right)W$$

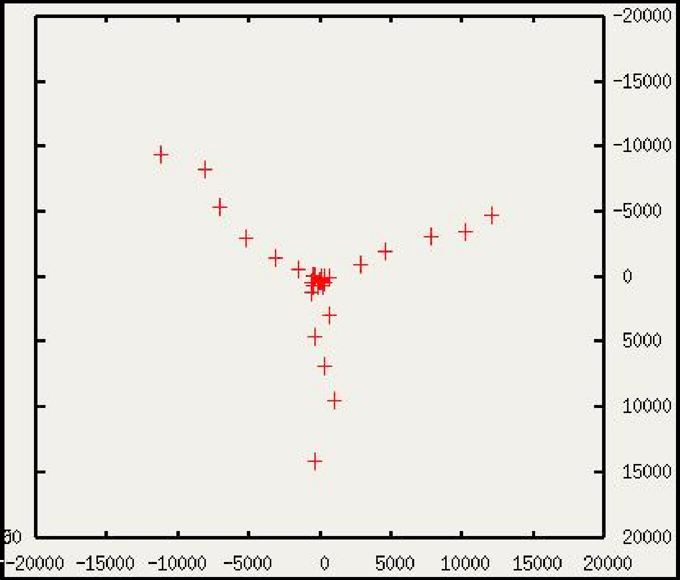
Priority	name	M (Jup)	a (AU)	dist (pc)	Flux1 (mJy)	Gal Lat
1	tauboo	***5.2***	0.05	15.6	***717.8***	***-73.9***
2	HD162020	2.4	0.21	***4.7***	43.6	59.6
3	HD179949	1.2	0.04	27.0	211.1	15.8
4	70vir	9.3	0.48	18.1	1.6	-74.1
5	Upsandb	0.9	***0.06***	13.5	147.3	20.7

*Desh. M. D., and M. L. Kaiser, *Nature*, *310*, 755, 1984;
Farell, W. M., et al., *Geophys. Res. Lett.*,, 2003;
Zarka, P., R. A. Treumann, B. P. Ryabov, and V. B. Ryabov, *Astrophys. and Space Science*, *277*, 293, 2001.
Lazio, T.J.W., W.M. Farrell, J. Dietrick, E. Greenlees, E. Hogan, C. Jones, and L.A. Hennig, *Astrophys. J.*, 2004.

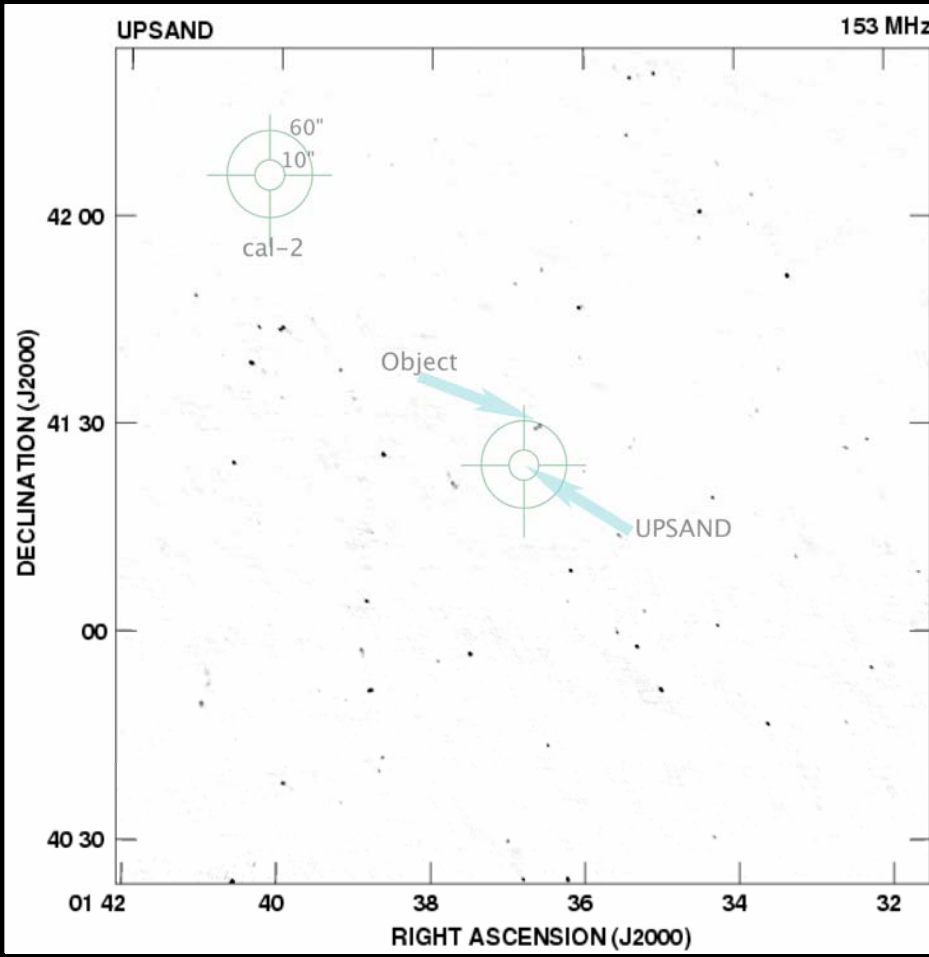
THE GIANT METERWAVE RADIO TELESCOPE (GMRT)

GMRT is the largest fully steerable telescope operating at meter wavelengths. Currently, its lowest operating frequency is 150 MHz.

The facility, located near Pune, India, consists of 30 individual 45 meter dishes.



THE GIANT METERWAVE RADIO TELESCOPE (GMRT)



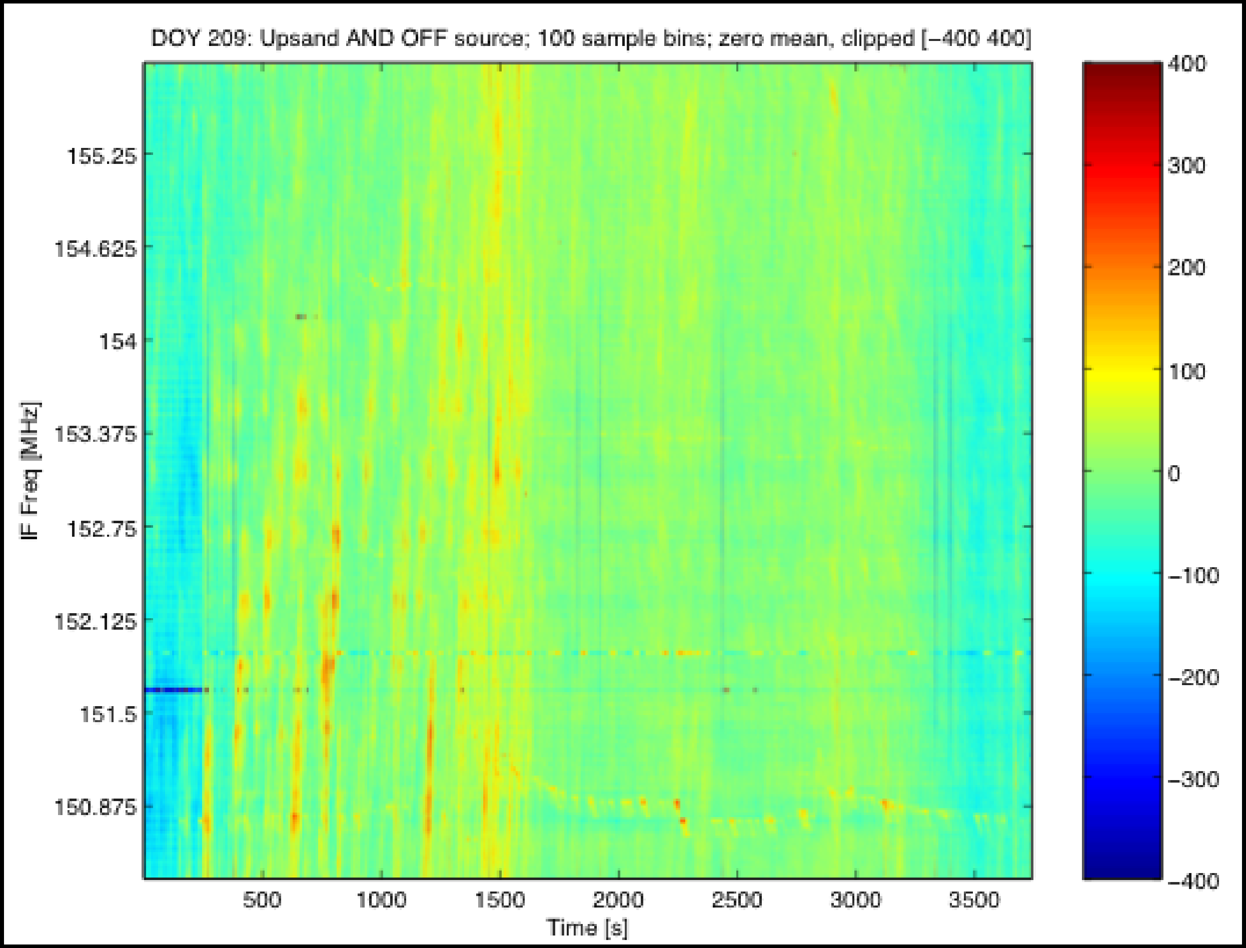
- **GMRT map of UPSAND region in 153 MHz.**
- **Beam size ≈ 60 arcseconds.**
- **1 hr integration, 5 MHz bandwidth.**
- **RMS Noise: 3 mJy *(expected signal 147 mJy)***
- **Nothing seen.**

Interferometry Mode

- for maps
- time resolution 512 msec
- bandwidth 8 MHz - 5.5 MHz
- 256 spectral channels
- spectral resol. 15-31 KHz

- spatial resolution ≈ 20”

Pilot Observations at GMRT

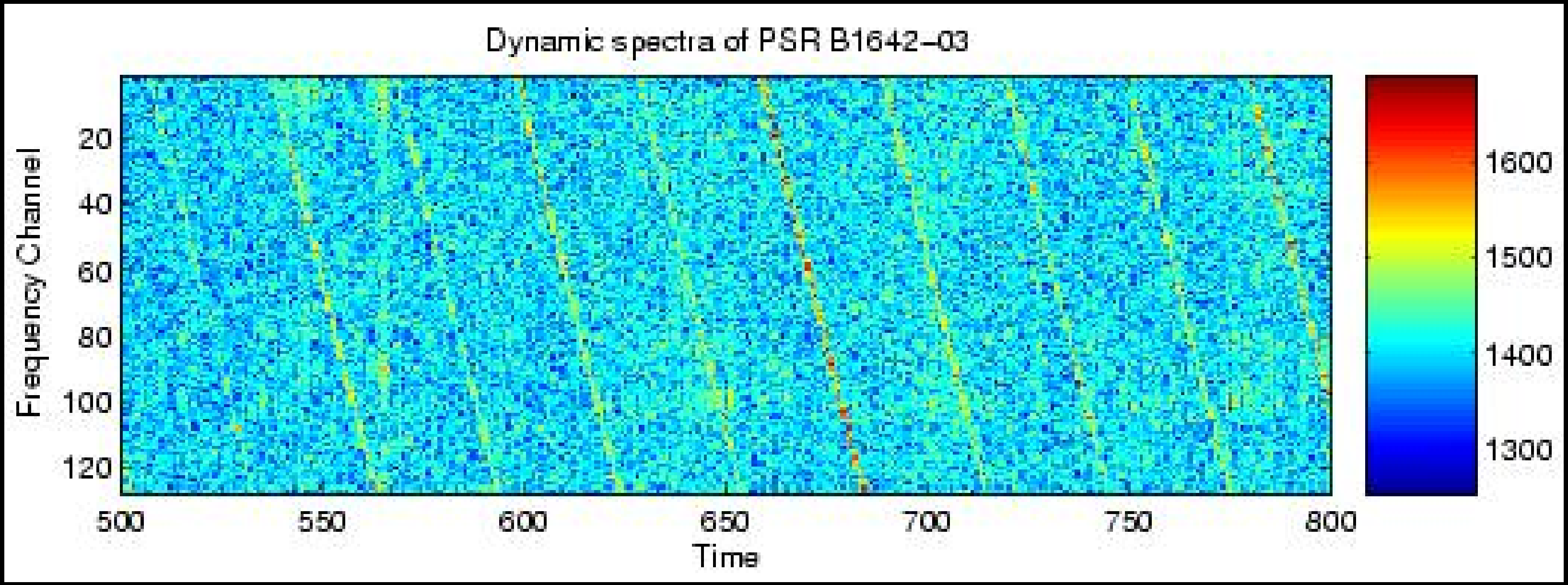


- **UpsAnd ON source and OFF source**
- **100 sample bins.**
- **Zero mean.**
- **Clipped [-400, 400].**
- **Signal??? (probably not…)**

Pulsar Mode

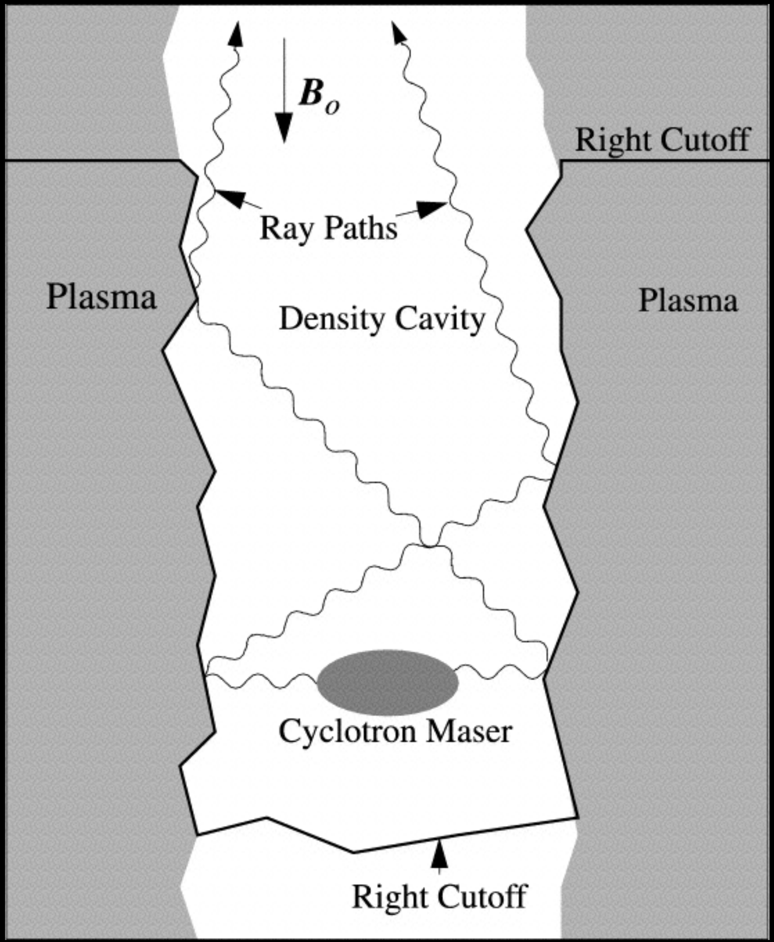
- for dynamic spectra
- CSQ antennas
- time resol. 512 µsec
- bandwidth 4-8 MHz
- spectral resol. 15 - 31 KHz
- synthesized beam size 7'

GMRT Pilot Obs



PSR B1642-03: P~0.4s, DM~36cm^{-3}pc, S1400~20mJy

Model of Cyclotron Maser



Operating in a denstiy cavity [Ergun et al., ApJ, 538, 456, (2000)].

Typically, the radio emission is generated close to the electron gyrofrequency.

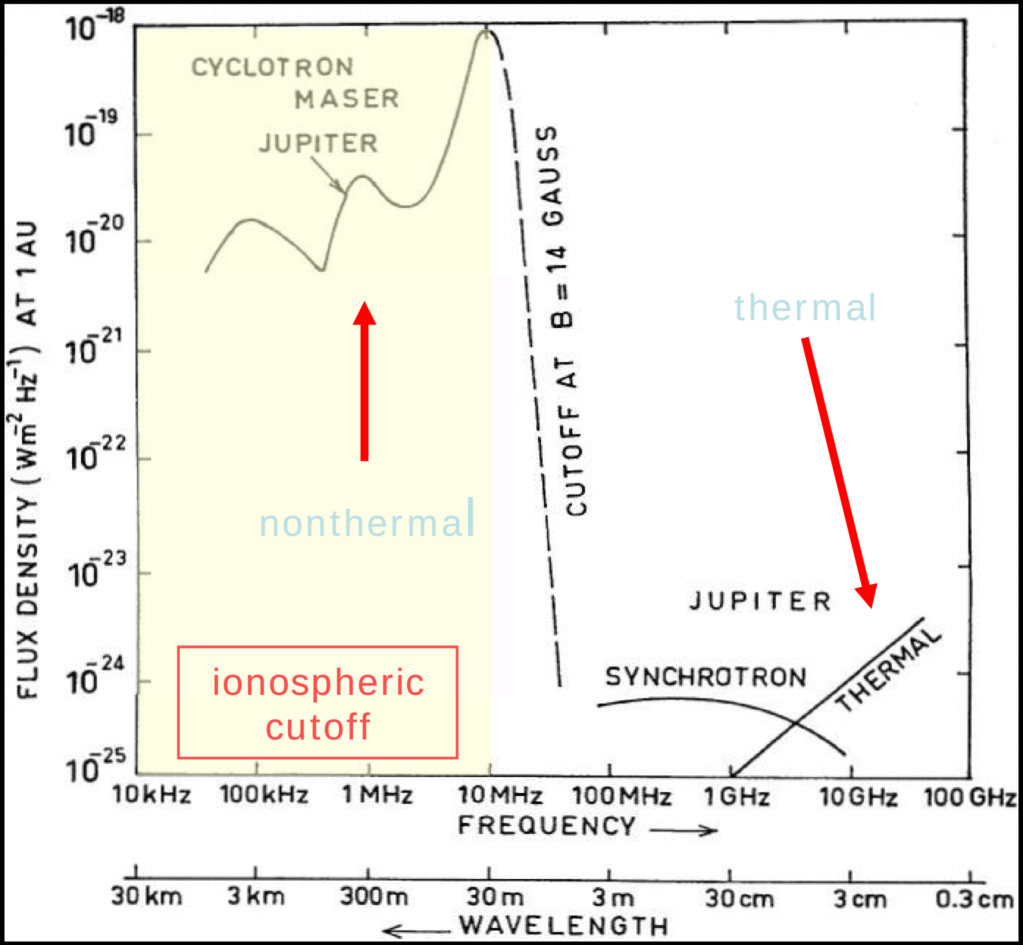
The emission mechanism probably is the Cyclotron Maser Instability (CMI), a wave-particle-interaction involving electrons gyrating in a magnetic field.

Instability, i.e. positive growth rates require the distribution function to fulfil the condition:

$$\partial \mathbf{f} / \partial \mathbf{v}_{\perp} > 0$$

This is true for loss-cone and horseshoe distributions.

Planetary Radio Emission



Thermal (black-body) and nonthermal emission of this solar system's radio planets (normalized to a distance of 1AU).

[Bastian, Dulk, Leblanc, ApJ, 545, 1058, (2000)]

Planetary Radio Emission

Jupiter's Flux Density at ~ 30 MHz	
4.5 AU	~ 50,000 Jy
10 pc	~ 0.0000002 Jy

$1\ \text{Jy} = 10^{-26}\ \text{W m}^{-2}\ \text{Hz}^{-1}$

Radiometric Bode's Law

- The emitted power scales with the received stellar wind power [Farrell et al., JGR, 104, 14025, (1999)]:

$$\mathbf{P_{rad} \propto (P_{SW})^{1.2}}$$

- The received solar wind power depends on the cross-section of the magnetosphere:

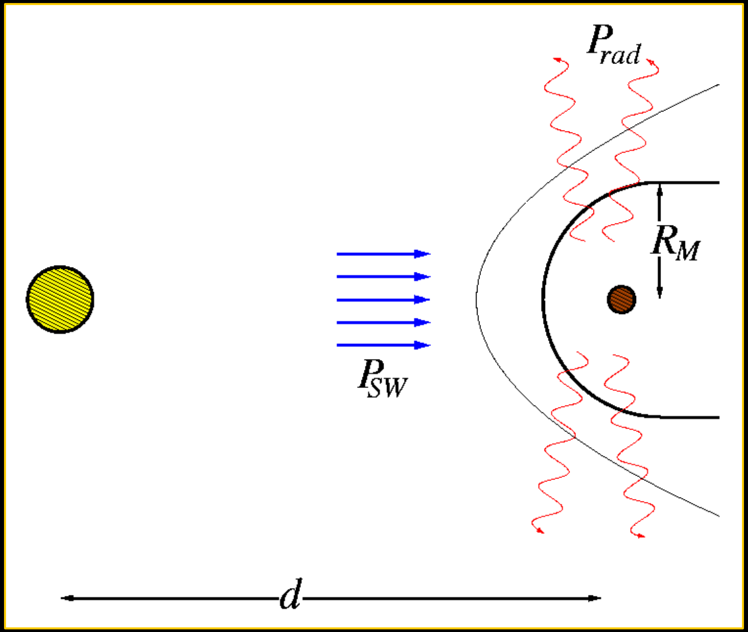
$$\mathbf{P_{SW} \propto (R_M)^2 d^{-2}}$$

- The size of the magnetosphere depends on the planetary magnetic moment:

$$\mathbf{R_M \propto M^{1/3} d^{1/3}}$$

- For the magnetic moment, different scalings are in use [e.g. Grießmeier et al., A&A 2003]:

$$\mathbf{M \propto (\rho_c)^{1/2} \omega^{\alpha} (r_c)^{\beta}}$$

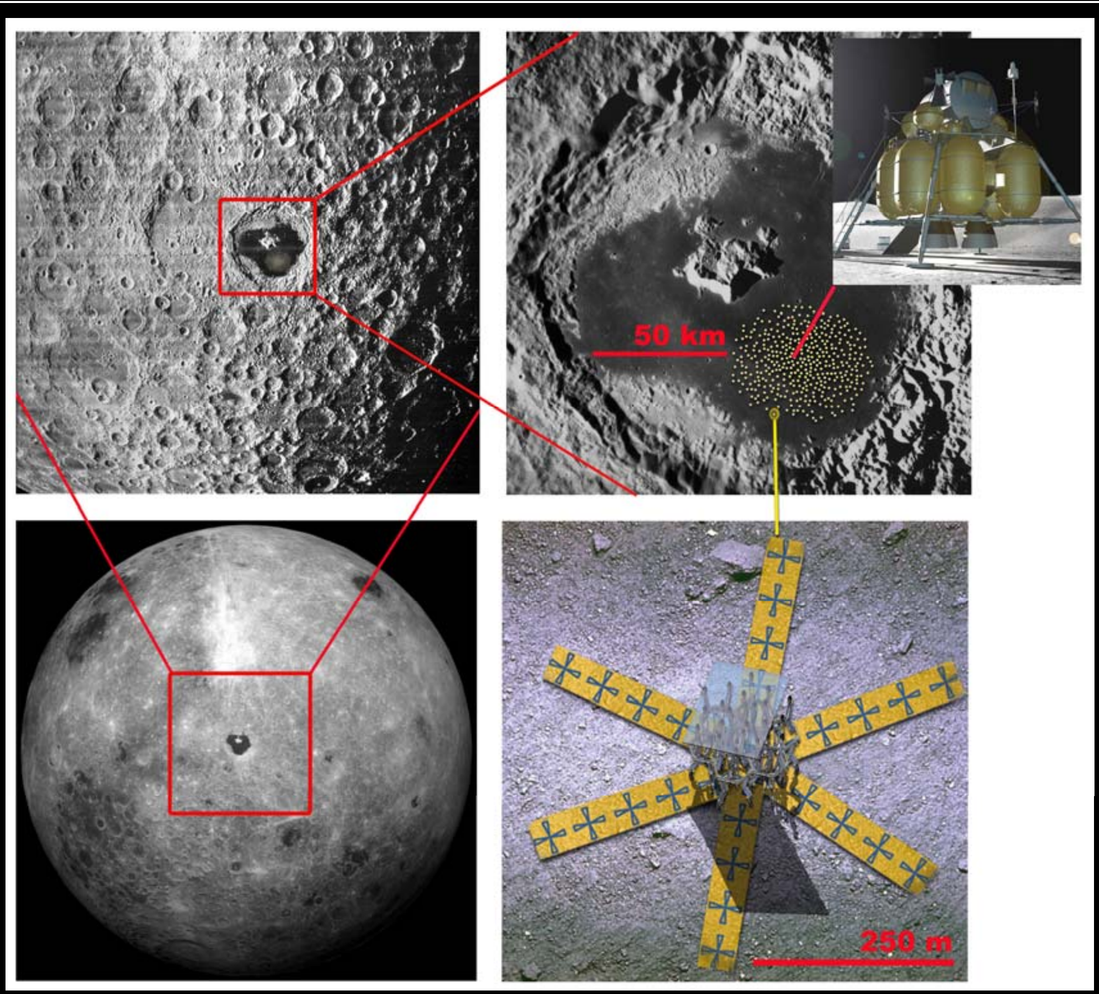


For close-in extrasolar giant planets (i.e. small ***d***), <u>much stronger radio emission</u> is expected than for Jupiter as long as they are not tidally locked (this would lead to smaller magnetic moments???).

Challenges

- Planets with weak magnetic fields will have cutoff frequency below ionospheric cutoff freq ~10 MHz.
- Galactic background and source confusion at low frequency
- How to disentangle planetary emission from stellar emission
- Beaming decreases probability of detection
- Emission may be too weak

Lunar Based Array



- **Lunar based low frequency array concept**
- **Science driver: <u>Epoch of reionization and also</u> radio emission from exoplanets, planetary and solar radio astronomy**
- **Solves RFI problem**
- **Mitigates ionospheric distortion the plagues low frequency obs on Earth**
- **Observations below the Earth's ionospheric cutoff frequency**

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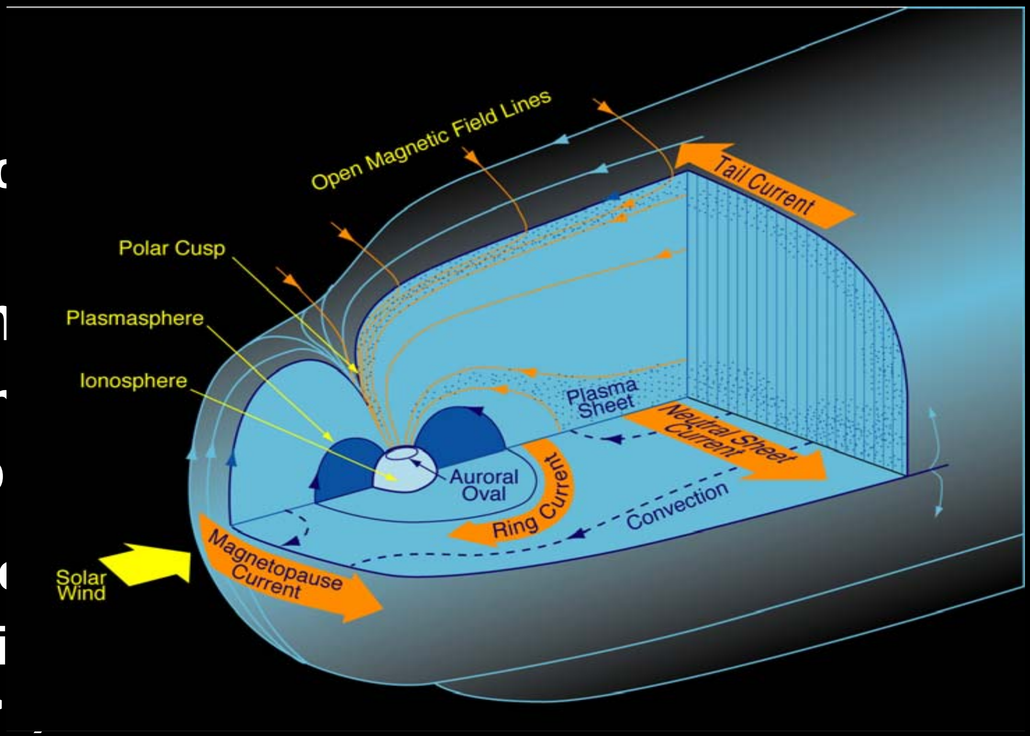
Planetary Magnetospheres

- **Magnetic planets:**
  - **Earth, Jupiter, Saturn, Uranus, & Neptune**
- **Magnetic field generated by rotation of conducting fluid**
  - **Earth: liquid iron core**
  - **Jupiter & Saturn: metallic**
  - **Uranus & Neptune: salty**
- **Planetary B-field is imm**
- **Pressure from solar wir magnetic field and defo**
  - **Deflect electrons relative**
  - **Explosive changes in tai yields currents (dB/dt -->**



Planetary Magnetospheres (cont)

- **Currents travel down highly conductive magnetic field lines and deposit energy in polar auroral region**
  - **1% of auroral input energy into electron cyclotron radio emission (Gurnett 1974)**
  - **1% of auroral input energy to visible/UV aurora**